INVESTIGATION OF THE EFFECT OF PULSING SHIELDING GAS IN ARC WELDING

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Abstract

Russian engineers have discovered a new method of delivering shielding gas for arc welding. This new method uses equipment known as the Gas Pulser™ to deliver an alternating or "pulsing" supply of two pure shielding gases which are input, creating an alternating supply of shielding gas delivered through a single gas line as opposed to the old method of using premixed shielding gas. The goal of this new "pulsing" method is to create a superior method of atmospheric protection for the molten weld pool.

Using this new machine and the equipment in The Ohio State University Welding Engineering Laboratory at the Edison Joining Technology Center, an investigation has been carried out to examine the effects of gas pulsing on weld deposits. Pulsed supplies of pure Argon and CO_2 shielding gases are being compared to mixed bottles of 90% Argon/10% CO_2 and 75% Argon/25% CO_2 to see the effects of arc performance. Gas metal arc welding (GMAW) is being used to weld a carbon steel T-joint located in the flat position. These T-joints were then cross sectioned and the weld profiles were examined for comparison of the effect caused by the pulsing gas supply.

The welding arc observed during the pulsing of the shielding gas produces an arc different from any other welding procedure resulting in a varying arc length and transfer as the two gases are pulsed. The arc experiences switching from globular transfer to short-circuiting within the welding puddle. This type of arc manipulation causes stirring in the molten weld pool and could be the primary cause for positive effects such as less spatter and porosity during welding. This stirring of the molten weld pool was also found to be causing positive effects on the weld bead when welding at higher travel speeds. In addition to these advantages, mixed shielding gas weld profiles have been compared to the pulsed shielding gases weld profiles using lower amounts of Argon shielding gas. If similar weld profiles can be accomplished by welding with less Argon and more CO_2, with the use of two pure gas bottles during the pulsing procedure, a great cost savings in shielding gas costs could be implemented.

Introduction

In GMAW, mixtures of two or more gases are often used to shield the arc and the molten weld pool in order to improve the fusion process and weld quality. These mixed gases can be premixed at a filling plant and delivered in a cylinder for use at a job site or two gases can be mixed at the job site using a gas blender or mixer. Shielding gas is very important in GMAW and therefore any change in gas mix or flow parameters greatly affects the arc transfer characteristics and resultant weld quality. The shielding gas system thus greatly impacts productivity and cost-effectiveness. The problem with the current shielding gas systems is mixed cylinders are expensive and gas mixers are often inaccurate, therefore more efficient, alternative shielding gas technologies are of interest.

This investigation will research a new alternative in shielding gas technology where alternating flows of two different pure shielding gases are feed through the welding torch. This shielding gas system uses a Gas Pulser™ which was recently introduced by KR Precision Co., Ltd. in South Korea. The company claims the Gas Pulser™ can overcome shortcomings of the conventional shielding gas systems and this investigation will determine if there are potential benefits to using this new system.

Background

Arc Welding

Arc welding is a fusion process for joining metals. Metal fusion occurs from the intense heat of the electric arc, causing melting and intermixing of the metals to be joined. As the material cools and solidifies, a metallurgical bond is created. The intense heat necessary in arc welding is provided by dissipation of electrical energy in the arc.

The high temperatures required to melt the metals in arc welding produce a chemical reaction with the oxygen and nitrogen in the surrounding air. Oxides and nitrides form and significantly reduce the strength and toughness of the material in the weld joint. Because of this, arc welding processes use some means of protecting the arc and the molten pool with a shield of gas, vapor, or slag. Arc shielding prevents contamination from atmospheric contact of the molten weld pool and filler metal.

In the GMAW process, chemically inert gases are predominately used to protect the molten metal pool from the air. GMAW can be seen in Figure 1, which is an arc welding process where an arc is produced between a continuous consumable filler metal electrode and the materials being welded.

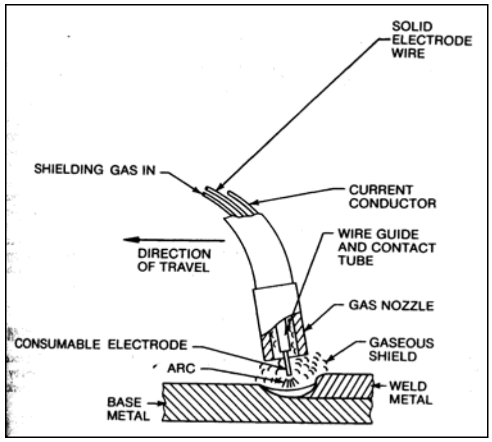


Figure 1: Schematic of the components within GMAW. (Ref. 1)

Shielding Gas

Three basic gases are commonly used to shield the weld pool from contamination. These gases are argon, helium, and carbon dioxide. In addition to the common shielding gases, small additions of oxygen and hydrogen have also proven beneficial for some welding applications. Argon and helium are the only chemically inert shielding gases used, while carbon dioxide is a chemically active gas that dissociates into carbon monoxide and free oxygen in the intense heat of the welding arc. This free oxygen then reacts with other elements in the molten weld pool. Pure CO_2 will not produce spray transfer in the arc, and is therefore restricted to short circuiting and globular transfer. The major disadvantage of carbon dioxide is the transfer limitations causing an increase in spatter, but it remains popular due to its availability, low cost, and weld performance. This gas is often used to weld carbon steel. Argon can be used alone or can be combined with other gases for welding ferrous and nonferrous metals. A variety of transfer modes can be accomplished with argon or its mixes to achieve good weldability, mechanical properties, and arc stability. Helium is used when high heat inputs are required and may improve wetting action, depth of fusion, and travel speeds. It produces weld pool fluidity, creating an advantage when welding aluminum, magnesium, and copper alloys. This gas is often mixed with argon. (Ref. 2)

The use of an individual shielding gas or a combination of shielding gases gives the ability to manipulate the metal transfer mode in GMAW. The primary metal transfer modes are globular, spray, and short circuit transfer. The transfer of metal through the arc stream of wire electrodes can be characterized as a globular (massive drops) or a showery spray (a large number of small drops). Globular and spray modes are rarely found alone as the material is generally transferred in some combination. Argon shielding gives the ability to produce a variety of metal transfer modes with GMAW. When welding with argon shielding gas, if the current is above the transition level, the transfer mechanism can be best described as an axial spray, and short circuits are nonexistent. However, when helium or an active gas such as carbon dioxide is used for shielding, the transfer is globular, and some short-circuiting may occur. In short circuit transfer of GMAW that can be seen in Figure 2, the wire consumable electrode is feed at a constant speed and makes contact with the workpiece or molten weld pool, at which time a short circuit occurs. When this happens, the current from the power supply increases and heats the wire to a point where the end of the wire melts off, creating an arc between the wire end and the workpiece. (Ref. 2)

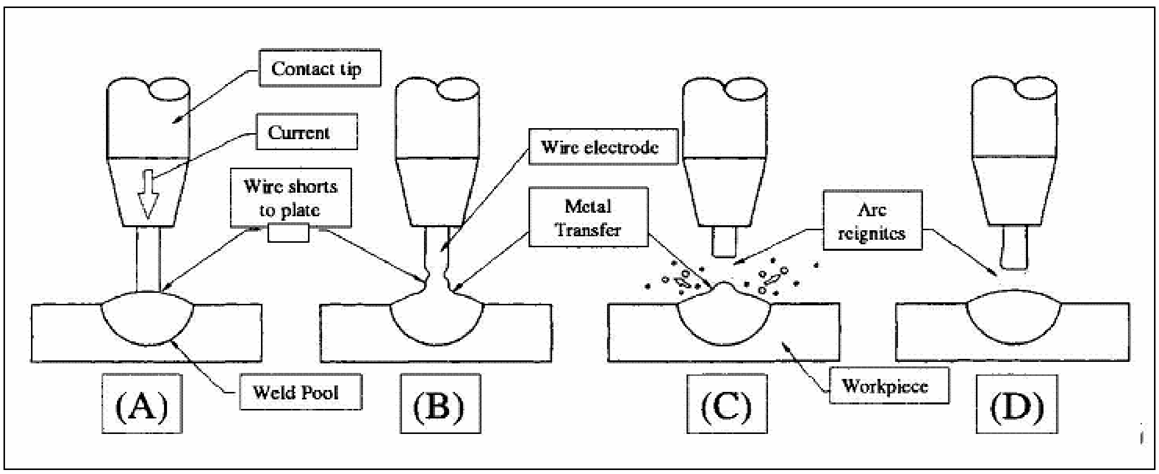


Figure 2: Schematic of Short Circuit Transfer GMAW showing the process of metal transfer. (Ref. 3)

Often time's mixtures of two or more shielding gases are used to produce some desirable affect on the fusion process and weld quality. The improvement in the fusion process and weld quality is possible because the different shielding gases have different properties, such as ionization potentials, which provide different arc temperatures and other properties. Mixed gases can be premixed at a filling plant and delivered in a cylinder for use at the work location, or can be mixed at the work location using a gas mixer.

Gas mixers are designed to supply shielding gas at a constant mix ratio at a constant flow rate during the welding process. The primary function of a gas mixer is to deliver the shielding gas at the desired gas mix under a wide range of flow conditions, but often the gas ratio is incorrect at the mixing stage or the gases tend to separate while traveling down the gas line.

Gas Pulser™

A new method, originally developed by Dr. O. M. Novikov for Russian spacecraft applications, alternates the supply of two pure gases for shielding during arc welding. This alternating shielding gas delivery is done using a machine to which two different shielding gases are connected and an alternating supply of the shielding gases is fed to the welding torch by a valving mechanism. This new method uses a machine known as the Gas Pulser™ manufactured by KR Precision Co. Ltd., a South Korean company that manufactures the "gas pulsing" machine to deliver an alternating or "pulsing" supply of two pure shielding gases which are input, creating an alternating supply of shielding gas delivered through a single gas line as opposed to the old method of using premixed shielding gas. A picture of the Gas Pulser™ and a schematic of the gas pulsing mechanism can be seen in Figure 3.

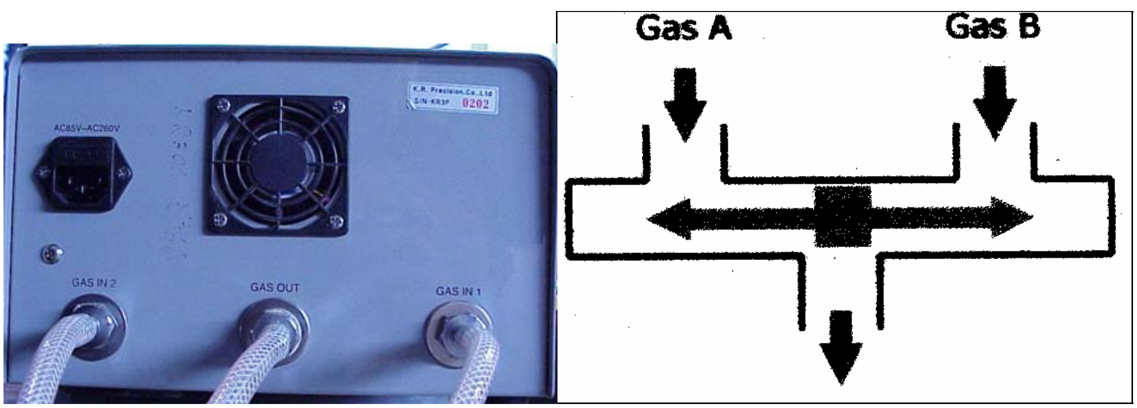


Figure 3: Left: Gas Pulser™ rear view showing the inputs and outputs for the shielding gases. Right: Schematic of the gas pulsing switching mechanism.

These alternating flows of different shielding gases can be manipulated by varying the flow rates of each gas and the frequency of switching or "pulsing". There are claims that this produces beneficial results in the weld deposit beyond straight mixing.

Two studies of this method were carried out by KR Precision Co. Ltd. The effects of alternate supply of shielding gases were studied for GMAW of aluminum and GTAW of austenitic stainless steel. In both cases, the alternating of pure argon and pure helium was compared to use of a conventional 33% argon + 67% helium mixture. In GMAW of aluminum, alternating delivery was claimed to produce a lower degree of weld porosity and a deeper and broader weld penetration profile. In GTAW of austenitic stainless steel, welding speed was increased without loss of weld penetration with less weld distortion found.

Objectives

The purpose of this investigation has been to systematically study the effects of gas pulsing on the weld deposit by examining the weld cross sections. The investigation will determine if the pulsing of two pure alternating shielding gases create potential benefits relative to the use of conventional gas mixtures.

Experimental Procedure

Weld Joint and Fixture

Carbon steel was the material chosen for the gas pulsing investigation as no past research had been carried out using this material. Also, carbon steel is a readily available and widely used material that is relatively inexpensive. A plate thickness of ½" was chosen for the GMAW process and the material was cut into 4" x 8" coupons.

Figure 4: Dimensions of the T-joint

Two carbon steel coupons were placed together in a fillet (T-joint) and positioned on a custom built fixture. The fixture was built for welding T-joints in the 1F (flat) position, the fixture consisted of two large steel pieces welded together at a right angle. For this to work properly, a slot was cut into one side of the fixture so that one of the flanges of the T-joint would extend underneath the fixture. For clarification a photograph of the welding fixture setup can be seen below in Figure 5.

Figure 5: End view of welding fixture.

Welding Equipment Setup

The arc welding process used in the investigation was GMAW. An automated GMAW system was chosen for ease of weld repetition to reduce welding variables. In Figure 6, the automated welding system can be seen including a Miller Invision 456P DC Inverter Arc Welder power source, Miller Travel Master SB-10D Side Beam Control, Miller Automatic M Microprocessor Weld Control, and a Miller Travel Master GMAW.

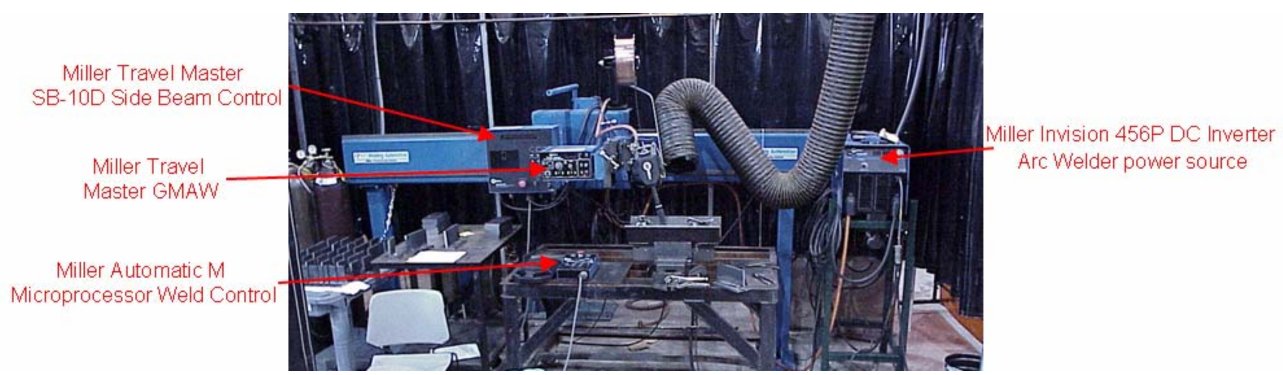


Figure 6: Miller automated welding system used for experimentation.

Shielding Gas Equipment

Argon and carbon dioxide gases were chosen for the comparison between premixed shielding gas and pulsing two pure shielding gases. The shielding gases used during experimentation were mixed 90% Argon/10% CO_2, mixed 75% Argon/25% CO_2, pure Argon, and pure CO_2. Using flow meters, the gas pulsing method was compared to the premixed gases by creating gas ratios similar to 90% Ar/10% CO_2, mixed 75% Ar/25% CO_2. The flow of these shielding gases was measured in standard cubic feet per hour (SCFH) with gas cylinder flow meters that can be seen in Figure 7.

Figure 7: Shielding gas bottles of CO_2 and Argon with flow meter gauges.

The total flow setting was set to 70 SCFH for both the premixed and pulsing tests because of the maximum limit of the Gas Pulser™ machine. This was accomplished by setting the flow meter at 70 SCFH for the premixed gas and by using a sum of the two pure gases for gas pulsing. The Gas Pulser™ machine, shown in figure 7, was obtained on a loan basis from KR Precision Co., Ltd. to alternate (pulse) shielding gases.

Figure 8: Front view of the KR Model 301 Gas Pulser™ machine.

The Gas Pulser™ machine features a front display used to set the desired gas pulsing frequency setting. When setting the frequency, the two digits on the display are set the same, as with the 0 0 display shown in Figure 8. The display has ten possible settings of 0 0 – 9 9 which reflect the different frequencies shown in table 1.

Table 1: Frequency chart for the KR Model 301 Pulser™ machine.

KR Model 301 Frequency Chart	
Display	Frequency (Hz/sec)
0 0	12.5
1 1	8.3
2 2	6.2
3 3	5
4 4	4.1
5 5	3.5
6 6	3.1
7 7	2.7
8 8	2.5
9 9	2.2

Welding Procedure

Familiarity with the automated Miller welding system was obtained by welding scrap steel material during the pre-experimental stage. The Miller Automatic M Microprocessor Weld Control was used to input the welding variables including travel speed, voltage, and WFS. Alignment between the welding torch and fixture was achieved for travel by running the welding torch back and forth along the T-joint and adjusting the alignment. After this initial investigation, it was determined that the ½" thick carbon steel base metal would be welded with Lincoln ER70S-6 0.45 inch solid welding wire. Additionally, the welding nozzle was positioned at a forehand angle of 15° with a contact to work distance (CTWD) of 7/8 inch.

The Arcwise method was used for establishing the nominal GMAW operating variables to provide a desired weld size. This technique relies on tying variables together based on a constant wire feed speed to welding travel speed ratio (WFS/TS). If this ratio is held constant, a constant deposited cross sectional area of the weld is maintained while the travel speed and current (WFS) are varied. Holding a constant deposited cross sectional area of the weld is very important as welded joints are designed for a particular deposited cross section. The weld size chosen for this experiment with 1/2" thick base material was 3/8". The equation used to calculate the WFS/TS ratio is given below were DA is deposited area, TS is travel speed, WFS is wire feed speed, WA is wire cross section, and f_d is deposition efficiency (assume process efficiency is 1). (Ref. 3)

For the Chosen Welds:

$$DA \times TS = WFS \times WA \times f_d$$

$$DA = ½(h)^2 = .5(3/8)^2 = 0.0703125 \text{ in}^2$$

$$WA = \pi(d/2)^2 = \pi(.045''/2)^2 = 0.00159 \text{ in}^2$$

Thus: $WFS/TS = DA/WA = 44.2$

After training on the automated welding system and calculating the WFS/TS ratio, a nominal travel speed was investigated by test welding. The 44.2 WFS/TS ratio was used to weld at a travel speed of 10, 11, and 12 inches/minute. The Lincoln Electric GMAW manual recommended these travel speeds. Two welds were made for each of these wire feed speeds using a mixed bottle of $90Ar/10CO_2$ at voltages of 30 and 32. These welds were cross sectioned and the weld size from using 11 inch/min was found to give the closest measurements to 3/8". Using the starting parameters of 11 inch/min at a WFS of 486 inch/ min, the first two phases of the investigation were conducted to compare the effects of shielding gas pulsing versus premixed shielding gas. The third phase of the investigation used the WFS/TS ratio found to explore shielding gas pulsing for higher travel speeds. The welding runs can be seen in Table 2 and the corresponding cross section measurements can be seen in Table 3.

Phase one of the investigation explored the characteristics of the Gas Pulser™ machine and the effects of changing the frequency, voltage, and shielding gases. A low (2.2 Hz), medium (4.1 Hz), and high (12.5 Hz) frequency setting was chosen from the frequency chart for the KR Model 301 Pulser™ machine that can be seen in Table 1 which shows the frequency settings in cycles per second (C/S) for each display setting. With a WFS setting of 486 inch/min., voltages of 30 and 32 were chosen to investigate. Finally the shielding gas flow settings were investigated versus the premixed shielding gas.

Phase two of the investigation experimented further with the effects of using greater percentages of carbon dioxide gas versus argon gas. Welds were made with premixed 90% Argon/10% CO_2 and premixed 75% Argon/25% CO_2 for a parallel comparison to the Ar/CO_2 ratios used with the gas pulser. The Ar/CO_2 ratios were taken past the premixed ratios with the Gas Pulser™ and the CO_2 flow settings were run until a maximum setting was found. The welding cross sections were examined for this phase to determine if a cost savings can occur from substituting a higher percentage of CO_2.

Phase three of the investigation experimented with the past claims of gas pulsing improving weld quality at higher travel speeds. Premixed 90% Argon/10% CO_2 and premixed 75% Argon/25% CO_2 were again used with similar gas pulsing Ar/CO_2 flow ratios to compare welding performance at the various welding speeds. In order to keep a consistent weld size, the wire feed speed (WFS) was increased accordingly to hold the same WFS/TS ratio. The welding cross sections and weld beads were then examined to determine if the Gas Pulser™ is capable of increasing production levels by welding at higher travel speeds.

After welding runs were carried out, the fillets welds were cross sectioned. These cross sections were then macro polished. After the cross sections were polished, the samples were etched with 5% Nital for 30 seconds. These cross sections were then labeled numerically by run number and macro-photographed with a Canon digital camera. These pictures were uploaded into Photoshop and the deposited cross sectional areas were measured after a pixel conversion. Next the legs, weld sizes, actual throat and effective throat, theoretical throat, concavity, and convexity was measured with digital calipers for each of the deposited cross sections. An illustration of these measurements can be seen in Figure 9 which is sourced from the American Welding Society (AWS) Committee on Methods of Inspection, 2000, *Guide for the Visual Examination of Welds,* AWS B1.11:2000, Miami: American Welding Society.

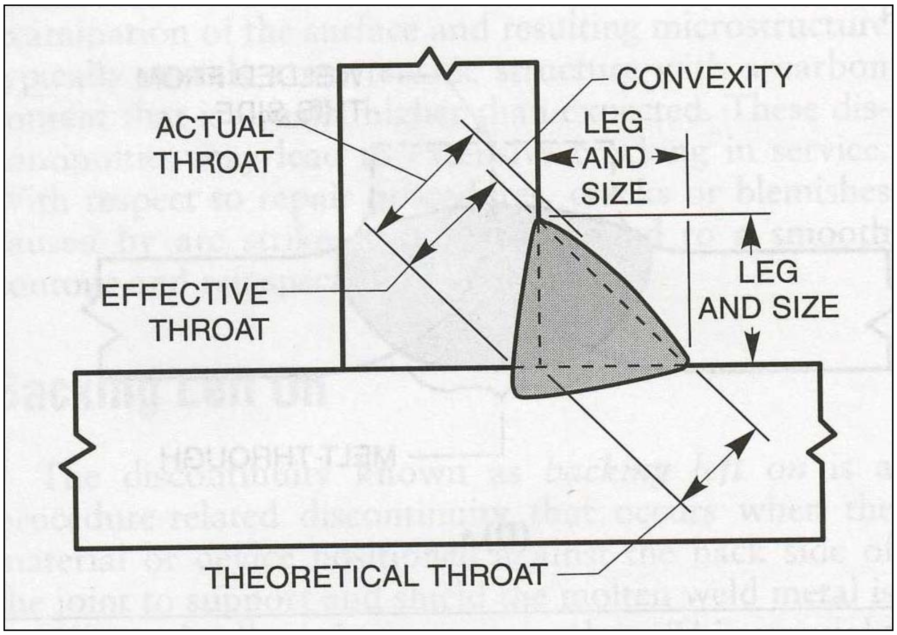


Figure 9: Fillet Weld Measurements

Table 2: Welding Run Procedures

Run #	Gas Supply	Ar/CO2 Gas Ratio	Ar Flow (SCFH)	CO2 Flow (SCFH)	Total Flow (SCFH)	Gas Freq (C/S)	WFS (in/min)	TS (in/min)	Voltage
1	mixed	90/10	NA	NA	70	NA	486	11	32
2	mixed	90/10	NA	NA	70	NA	486	11	30
3	pulse	86/14	60	10	70	2.2	486	11	32
4	pulse	86/14	60	10	70	2.2	486	11	30
5	pulse	86/14	60	10	70	4.1	486	11	32
6	pulse	86/14	60	10	70	4.1	486	11	30
7	pulse	86/14	60	10	70	12.5	486	11	32
8	pulse	86/14	60	10	70	12.5	486	11	30
9	pulse	79/21	55	15	70	2.2	486	11	32
10	pulse	79/21	55	15	70	2.2	486	11	30
11	pulse	79/21	55	15	70	4.1	486	11	32
12	pulse	79/21	55	15	70	4.1	486	11	30
13	pulse	79/21	55	15	70	12.5	486	11	32
14	pulse	79/21	55	15	70	12.5	486	11	30
15	mixed	90/10	NA	NA	70	NA	486	11	32
16	pulse	86/14	60	10	70	2.2	486	11	32
17	pulse	86/14	60	10	70	4.1	486	11	32
18	pulse	86/14	60	10	70	12.5	486	11	32
19	mixed	75/25	NA	NA	70	NA	486	11	32
20	pulse	75/25	52.5	17.5	70	2.2	486	11	32
21	pulse	75/25	52.5	17.5	70	4.1	486	11	32
22	pulse	75/25	52.5	17.5	70	12.5	486	11	32
23	pulse	64/36	45	25	70	2.2	486	11	32
24	pulse	64/36	45	25	70	12.5	486	11	32
25	pulse	29/71	20	50	70	2.2	486	11	32
26	pulse	50/50	35	35	70	2.2	486	11	32
27	mixed	90/10	NA	NA	70	NA	663	15	32
28	pulse	86/14	60	10	70	2.2	663	15	32
29	mixed	75/25	NA	NA	70	NA	663	15	32
30	pulse	75/25	52.5	17.5	70	2.2	663	15	32
31	mixed	90/10	NA	NA	70	NA	751	17	32
32	pulse	86/14	60	10	70	2.2	751	17	32
33	mixed	75/25	NA	NA	70	NA	751	17	32
34	pulse	75/25	52.5	17.5	70	2.2	751	17	32

Table 3: Deposited Cross Section Measurements from Welding Runs in Table 2.

Run #	Deposited Area (pixels)	Deposited Area (in^2)	Vertical Leg (inch)	Horizontal Leg (inch)	Effective Throat (inch)	Theoretical Throat (inch)	Root Penetration (inch)	Convexity (inch)
1	18932	0.530	0.416	0.416	0.278	0.278	0.138	0.000
2	17419	0.488	0.413	0.347	0.293	0.248	0.120	0.045
3	17754	0.497	0.435	0.379	0.280	0.280	0.138	0.000
4	19070	0.534	0.425	0.401	0.298	0.298	0.166	0.000
5	17750	0.497	0.407	0.342	0.304	0.265	0.137	0.039
6	20490	0.574	0.385	0.376	0.286	0.253	0.141	0.033
7	19653	0.550	0.404	0.334	0.301	0.263	0.156	0.038
8	17078	0.478	0.397	0.384	0.296	0.269	0.096	0.027
9	19246	0.539	0.403	0.372	0.298	0.265	0.159	0.033
10	17739	0.497	0.385	0.385	0.294	0.259	0.140	0.035
11	19325	0.541	0.423	0.362	0.289	0.263	0.152	0.026
12	17057	0.478	0.378	0.379	0.303	0.261	0.108	0.042
13	19240	0.539	0.421	0.381	0.284	0.284	0.151	0.000
14	16858	0.472	0.360	0.368	0.298	0.261	0.098	0.037
15	18867	0.528	0.372	0.354	0.300	0.249	0.134	0.052
16	19607	0.549	0.417	0.385	0.294	0.265	0.135	0.030
17	17811	0.499	0.408	0.372	0.310	0.267	0.120	0.043
18	20259	0.567	0.428	0.376	0.292	0.268	0.124	0.024
19	19610	0.549	0.372	0.382	0.304	0.273	0.156	0.031
20	19262	0.539	0.391	0.379	0.310	0.262	0.129	0.048
21	19336	0.541	0.393	0.341	0.287	0.254	0.149	0.033
22	18535	0.519	0.387	0.358	0.306	0.251	0.125	0.055
23	19892	0.557	0.390	0.405	0.288	0.258	0.138	0.030
24	21734	0.608	0.391	0.366	0.306	0.266	0.159	0.040
25	19702	0.552	0.364	0.360	0.290	0.252	0.130	0.038
26	20540	0.575	0.380	0.372	0.298	0.262	0.159	0.036
27	21977	0.615	0.346	0.334	0.349	0.233	0.267	0.117
28	19916	0.558	0.373	0.408	0.323	0.270	0.158	0.054
29	21701	0.608	0.370	0.286	0.321	0.216	0.262	0.106
30	19448	0.544	0.369	0.347	0.322	0.259	0.226	0.063
31	21186	0.593	0.328	0.291	0.365	0.220	0.274	0.146
32	20587	0.576	0.356	0.333	0.335	0.240	0.277	0.096
33	19875	0.556	0.300	0.322	0.324	0.212	0.225	0.112
34	20714	0.580	0.356	0.317	0.334	0.230	0.260	0.104

Results and Discussion

Preliminary Testing

After the Arcwise method was used to find the WFS/TS ratio of 44.2, the proper weld deposited area was found with a weld size of approximately 3/8 inch using a TS of 11 in/min, WFS of 486 in/min, and voltages of 30 and 32. Runs 1 and 2 were cross sectioned and can be seen in Figure 10. The use of premixed 90% Argon/10% CO_2 produced a spray metal transfer within the arc.

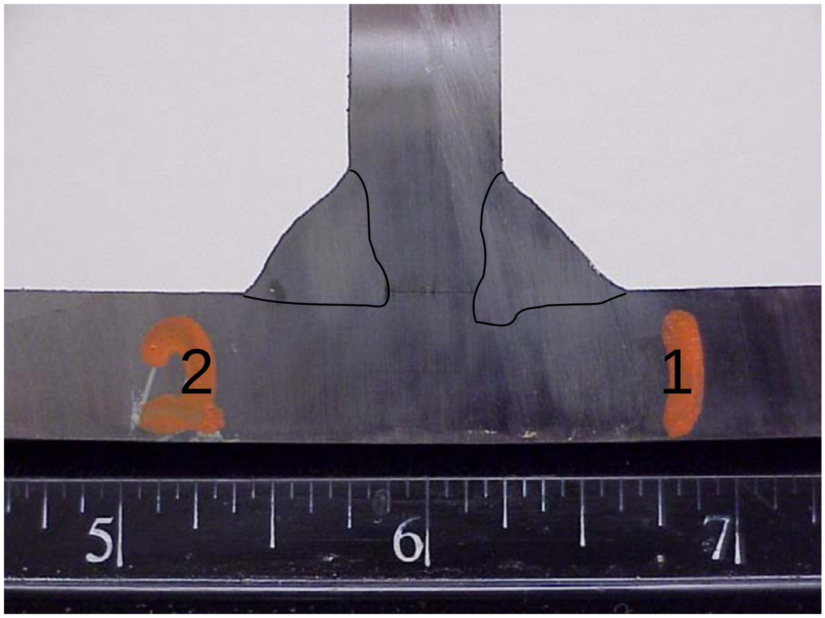


Figure 10: Cross Sections of Welding Runs 1 and 2

The Gas Pulser™ machine was then investigated using the variables found with the mixed bottle of 90%Ar/10%CO_2 shielding gas. Weld Runs 3-8, seen in Table 2, were made pulsing Ar at 60 SCFH and CO_2 at 10 SCFH giving 86%Ar/14%CO_2 percentage ratio for comparison to the premixed 90%Ar/10%CO_2 shielding gas. The Gas Pulser™ was used with low (2.2 Hz), medium (4.1 Hz), and high (12.5 Hz) frequency settings. These frequency settings revealed different arc performance as expected with each of the shielding gases flowing for different lengths of time. The high frequency setting of 12.5 (C/S) gave a more rapid arc switching as the argon and carbon dioxide pulsed. The low frequency setting of 2.2 (C/S) revealed greater arc variability as the two pure shielding gases were able to influence more with the greater flow pulsing time. This 2.2 (C/S) frequency setting also gave a more rippled bead appearance as can be seen in Figure 11. This medium setting of 4.1 (C/S) gave effects that were in-between these two settings as expected. When pulsing at this high argon gas flow percentage, the CO_2 had more influence on the arc as the frequency level decreased. This action occurs because the Ar had less influence since the CO_2 had more time to flow between pulses.

Figure 11: Welding Run 3

Welding Runs 9-14 were made with gas flows of Ar at 55 SCFH and CO_2 at 15 SCFH giving a 79%Ar/21%CO_2 percentage ratio. Frequency settings of low (2.2 Hz), medium (4.1 Hz), and high (12.5 Hz) were again investigated to determine if the greater flow level of CO_2 caused any changes. This section of testing was very similar to the previous welding runs and shows very similar deposited cross sectional areas (examine Runs 1-14 in A.1). These runs revealed a positive effect of the gas pulsing mechanism. This positive effect is the ability to duplicate weld bead cross section profiles using more carbon dioxide percentages than with premixed bottles. This finding gives a cost savings because pure bottles of shielding gas are cheaper than mixed gas. In addition, carbon dioxide is a cheaper gas than argon.

The arc produced by this shielding gas pulsing method appears to provide a change in metal transfer mode unlike normal transfer modes. During welding there was an odd variance between spray transfer, buried arc globular transfer, and short circuiting within the molten weld puddle as the pulsing mechanism operated. The short circuiting observed was the welding wire actually contacting the molten weld pool. The arc varied up to approximately a half of an inch during the switching from argon to carbon dioxide giving the molten weld pool a vigorous stirring effect. The arc length increases when argon is pulsed because of its spray transfer capabilities and changes to short circuit as the carbon dioxide surrounds the arc. This vigorous stirring has potential benefits to the weld as it can lower the amount of porosity, gives a finer microstructure, and gives more even distribution of the weld bead.

Preliminary testing revealed the direction worth investigating for the gas pulsing mechanism. The voltage changing did not reveal anything while pulsing so a voltage setting of 32 volts was used until higher current levels were investigated. The low frequency setting of 2.2 (C/S) gave the most relevant effects for the pulsing mechanism as each of the shielding gases have a greater influence on the arc between pulsing.

Experimental Welding

The next set of welding runs explored the limit of carbon dioxide shielding that could be used. For a comparison to mixed shielding gas use, Run 15 used 90%Ar/10%CO_2 mixed shielding gas and Run 19 used 75%Ar/25%CO_2 mixed shielding gas. The increase in carbon dioxide flow rates compared to argon shows small differences in the weld cross section profiles. The carbon dioxide level was raised all the way to a 71% flow rate compared to argon and still gave a similar weld cross section, but this level of carbon dioxide gave larger amounts of spatter during welding. The 50% carbon dioxide flow rate level was found to be the optimal setting for performance and gas cost savings. This setting had minimal spatter with a very similar weld bead cross section profile to the mixed shielding gas welds. Evidence of this phenomenon can be seen in Figure 12, where CO_2 percentage levels were plotted versus root penetration levels comparing to the mixed shielding gas welds.

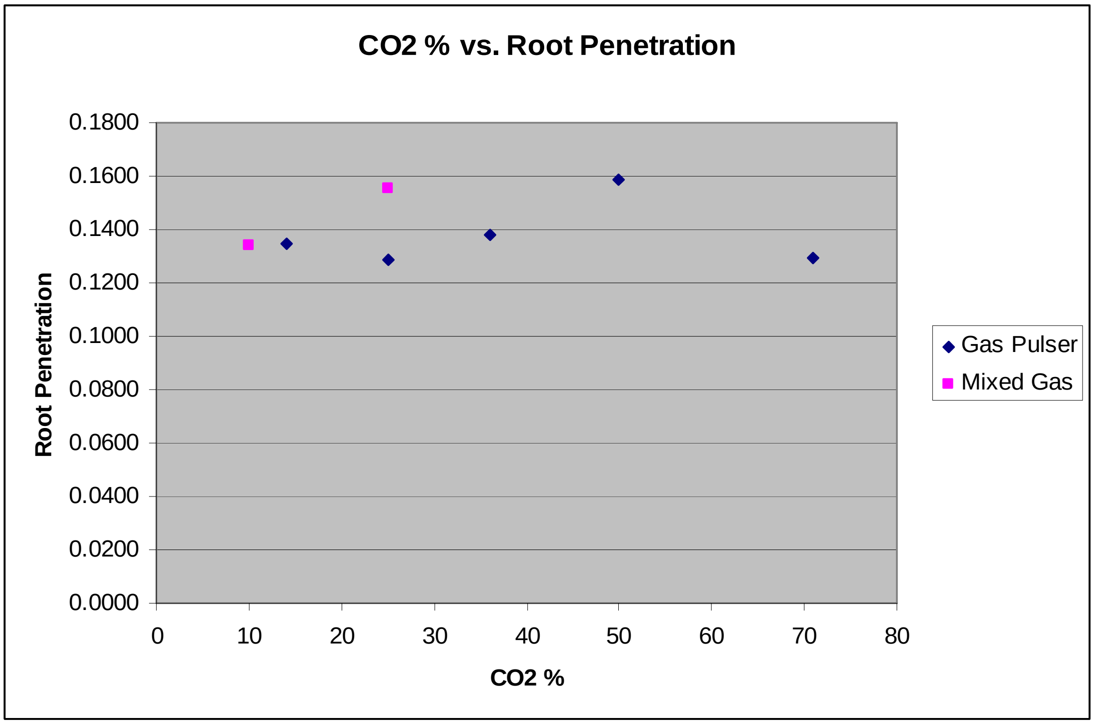


Figure 12: Plot of CO_2 percentage levels versus root penetration levels with comparison to mixed shielding gas welds.

Phase three of this research experiment investigated the effects of the gas pulsing mechanism when welding at higher travel speeds. Beneficial affects had been found in past research experiments using different materials. Welds were made with mixed shielding gas supplies for each different pulsed run for an equal comparison of the weld cross section profiles. For Runs 27-30, the travel speed was increased to 15 in/ min while also increasing the WFS to 663 in/min keeping the WFS/TS ratio constant. The carbon dioxide percentages were increased for 29 and 30 to reconfirm the weld cross section profiles for the higher TS. After observation of the cross sections, they revealed that the gas pulsing mechanism results in less concavity to the weld bead at higher travel speeds. The lower concavity observed in the welds may be due to the increase in weld pool stirring with the shielding gas in pulsing.

For runs 31-34, the travel speed was increased again to 17 in/ min while also increasing the WFS to the welding system's maximum level of 751 in/min keeping the WFS/TS ratio constant at 44. The carbon dioxide percentages were increased for 33 and 34 to reconfirm the weld cross section profiles while examining the higher TS. This higher travel speed shows that the pulsing mechanism can give raised production levels by getting a more evenly distributed weld bead at higher welding travel speeds as seen in Figure 13.

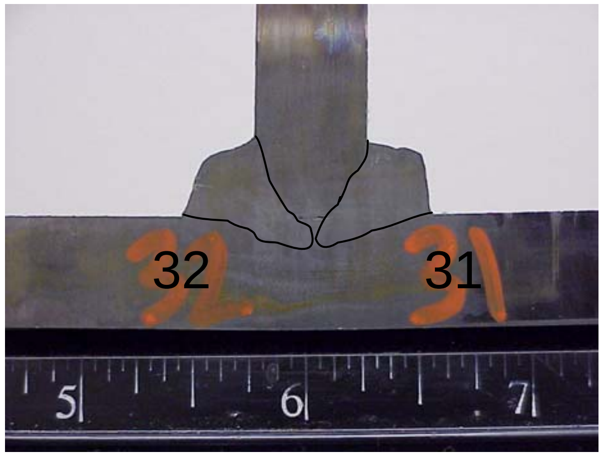


Figure 13: Welding Runs 31 and 32 showing difference in convexity.

In Figure 13, it can be seen that the convexity is significantly lower with the shielding gases being pulsed at higher travel speeds compared to mixed shielding gas.

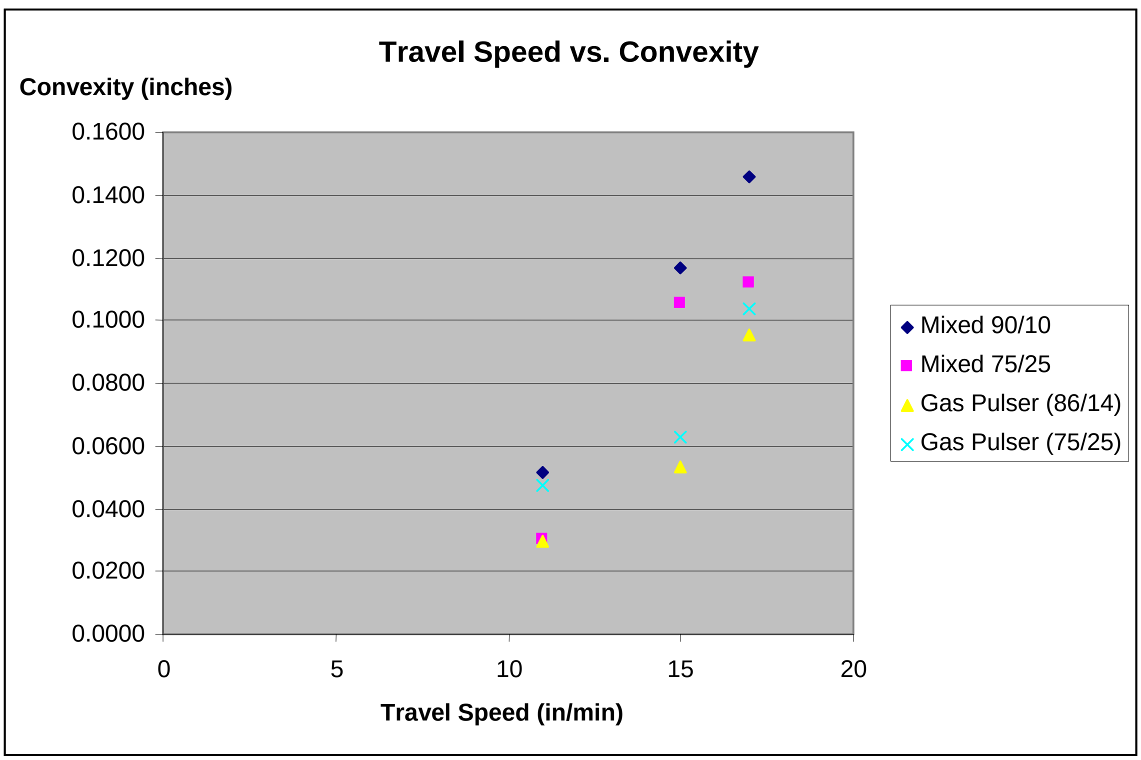


Figure 13: Comparison of mixed to pulsed shielding gas supply by plotting travel speed versus concavity.

Conclusions

1. Gas pulsing in GMAW causes the arc to vary in length as a result of oscillating metal transfer modes caused by alternating gases
2. Gas pulsing gives the ability to obtain similar penetration depths as mixed gas welds with greater ratios of CO2
3. Gas pulsing produces higher quality weld beads with less convexity at higher travel speeds

Future Work

Future research work with the Gas Pulser™ should involve a method of measuring the gas flow and chemistry of the gas exiting the torch. This could be done with a gas flow meter attached to the welding torch taking flow readings at the same pulse frequency as the Gas Pulser™. The chemistry composition of the shielding gas exiting the welding torch could be measured using laser spectrometry. With this information, a better understanding of pulsing shielding gas could be obtained.

The arc manipulation caused by the Gas Pulser™ could be better examined if captured on a high speed camera for a better visualization of the metal transfer. This would also give an opportunity to investigate the molten weld pool stirring the occurring during gas pulsing. This information could then be used to identify the effects of arc performance on porosity levels present in the weld.

Another separate investigation could use a gas mixer for more exact gas flow comparisons to the gas pulser ratios. This would give the opportunity to compare the shielding gas systems using the same exact gas flows, rather than just those commonly available as mixes.

This gas shielding system is fairly new and many different gases and arc welding processes could be researched.

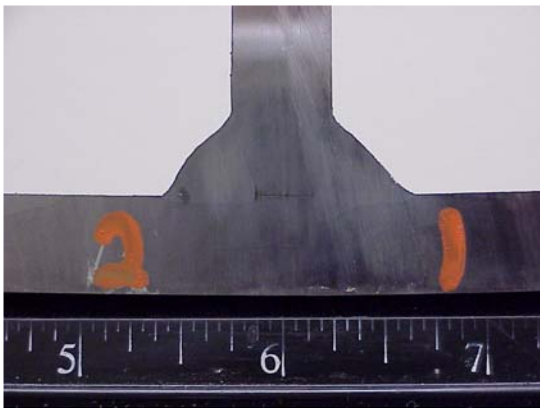
References

1. Welding Handbook, Welding Processes, Vol. 2, 8th Ed., pp. 75, 111. Miami, FL: American Welding Society, 1991.
2. GMAW Best Practices, Shielding Gases. Welding Journal, February 2006, 46-50.
3. Albright, Charles. WE 600 Course Notes

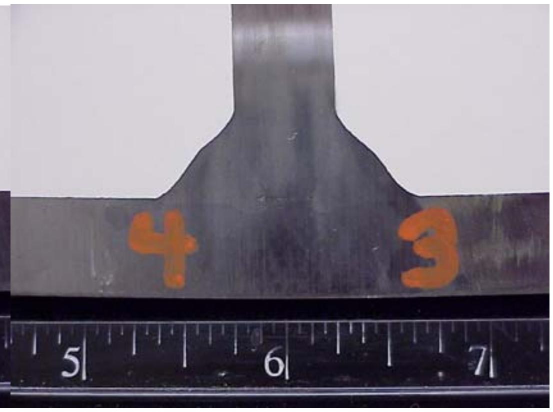
Appendix

A.1 Macrophotographs of Fillet Weld Cross Sections from Runs (1-34)

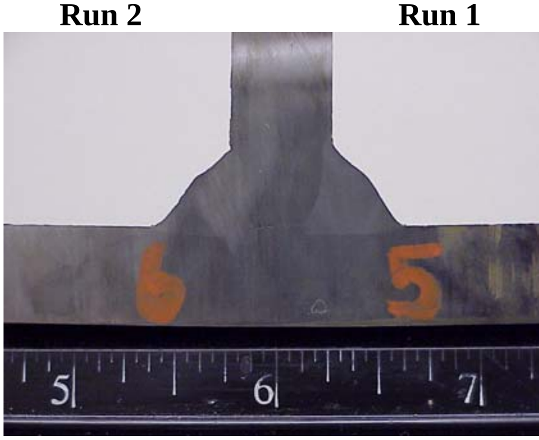
Refer to Table 2 for Welding Variables



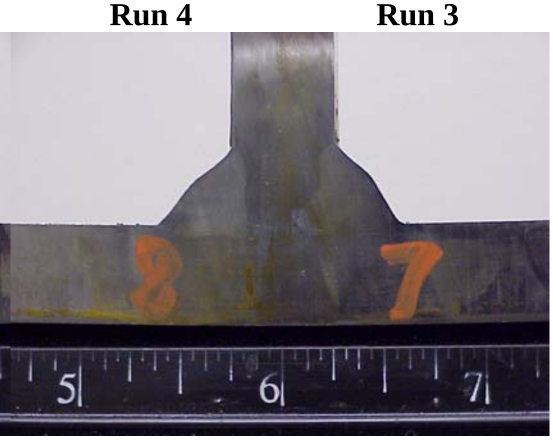
Run 2 **Run 1**



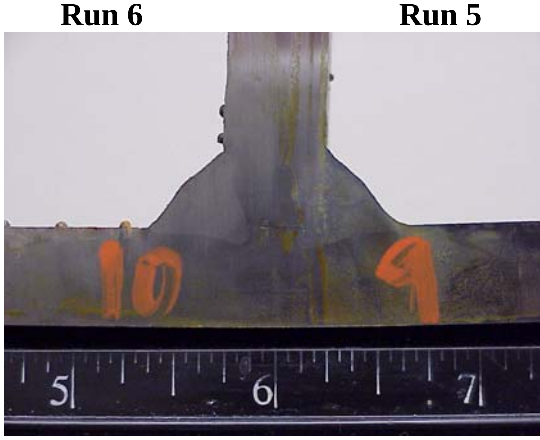
Run 4 **Run 3**



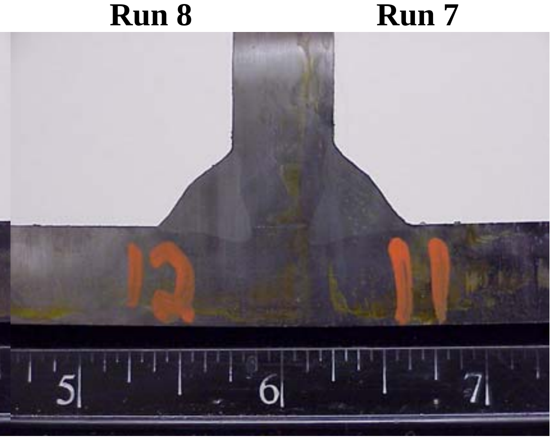
Run 6 **Run 5**



Run 8 **Run 7**

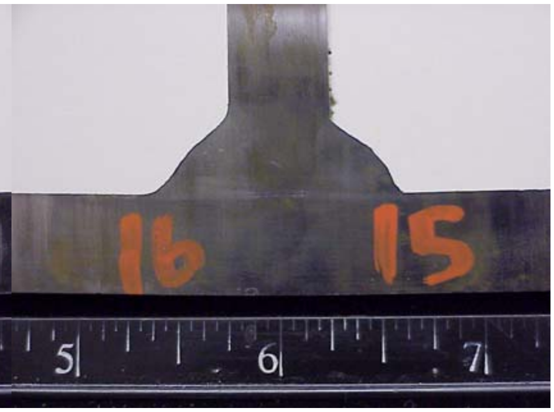


Run 10 **Run 11**

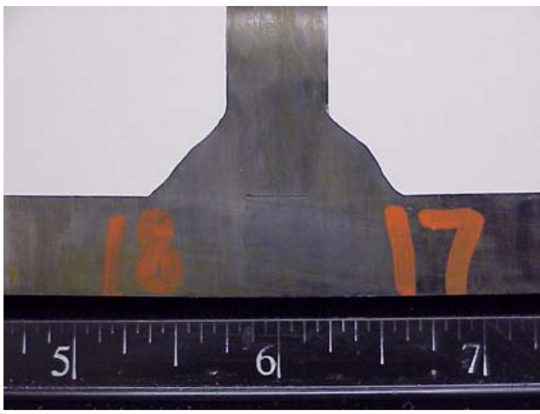


Run 12 **Run 11**

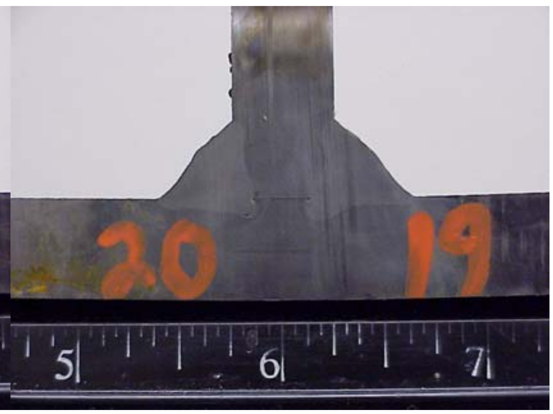
Run 14 **Run 13**



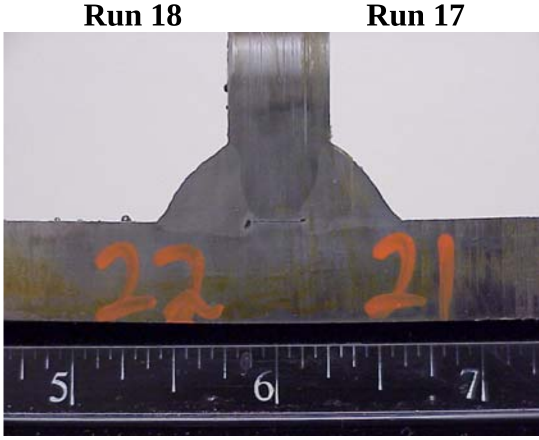
Run 16 **Run 15**



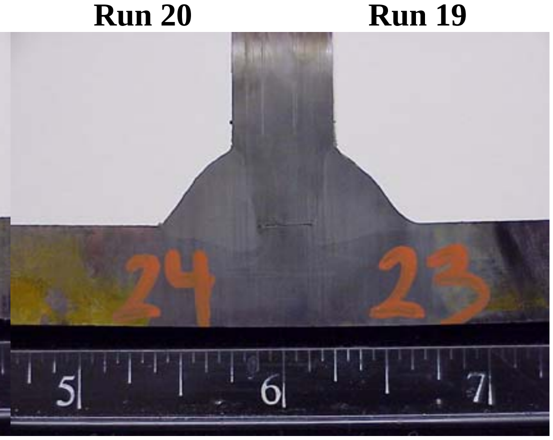
Run 18 **Run 17**



Run 20 **Run 19**



Run 22 **Run 21**

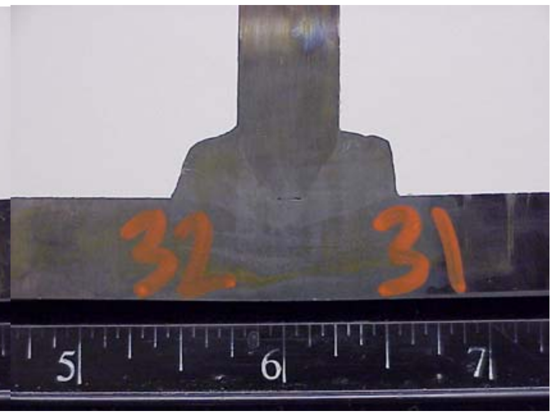


Run 24 **Run 23**

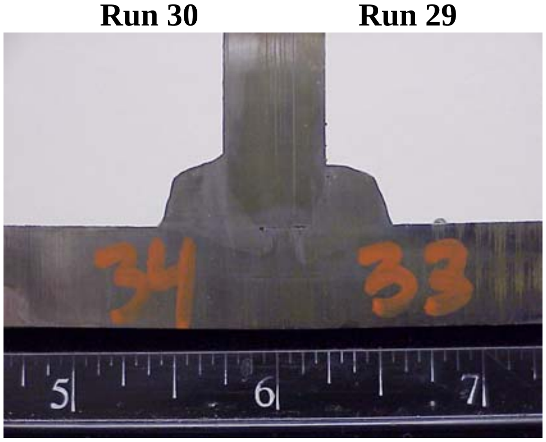
Run 26 **Run 25**

Run 28 **Run 27**

Run 30 **Run 29**



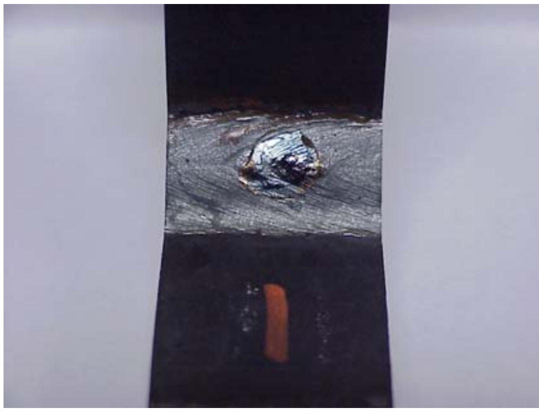
Run 32 **Run 31**

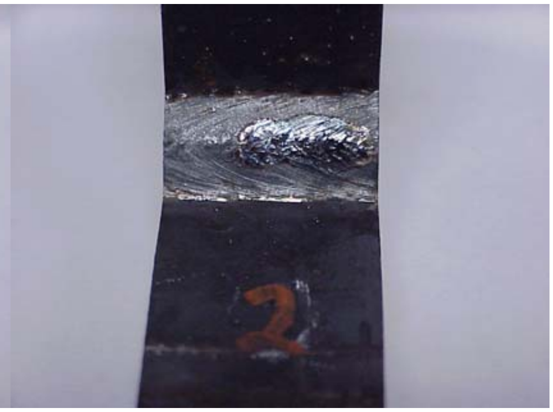


Run 34 **Run 33**

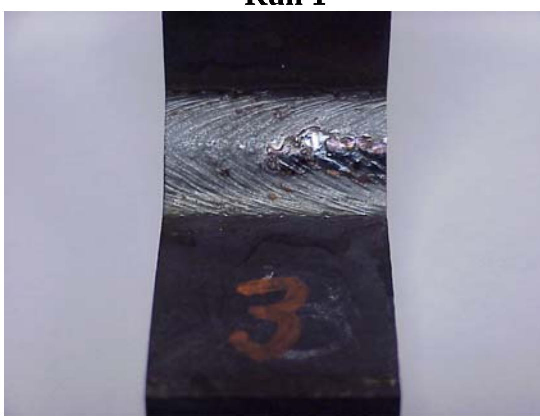
A.2 Photographs of Welding Run Beads (1-34)

Refer to Table 2 for Welding Variables

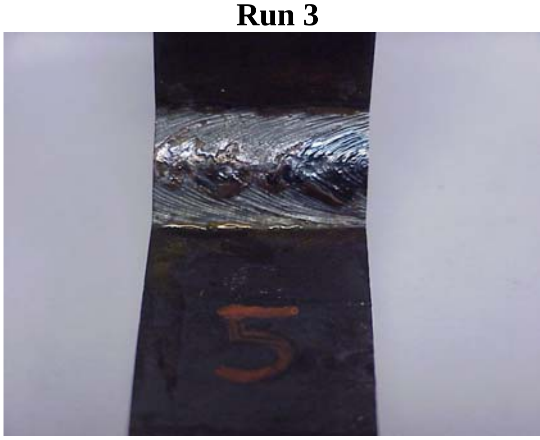


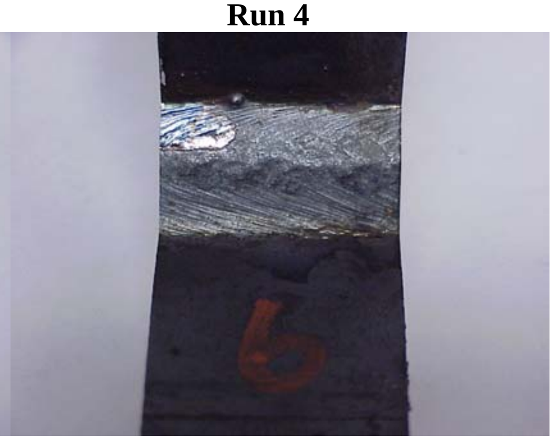


Run 1 **Run 2**

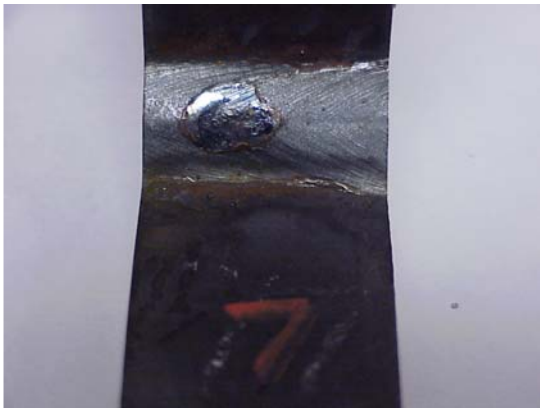


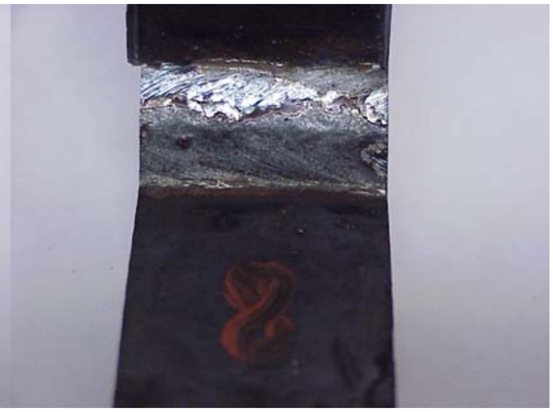
Run 3 **Run 4**





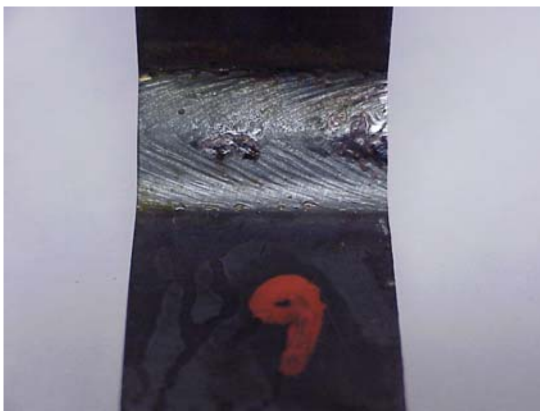
Run 5 **Run 6**

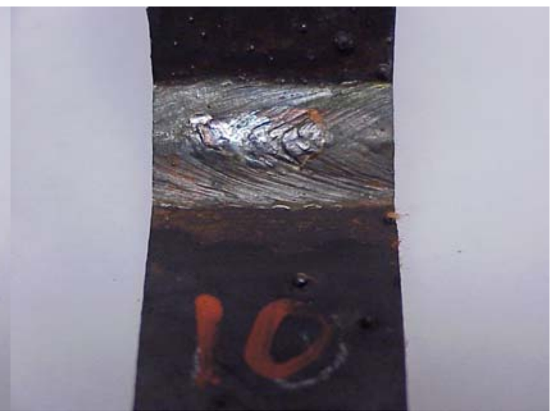




Run 7

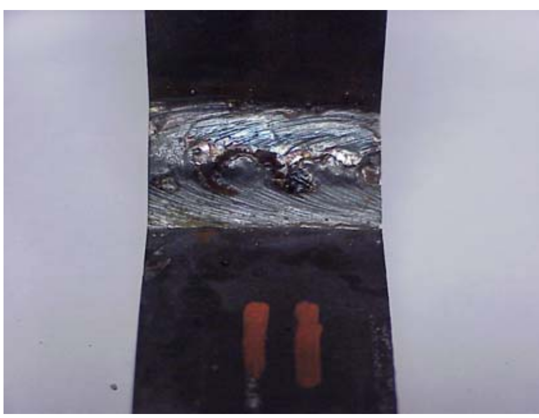
Run 8

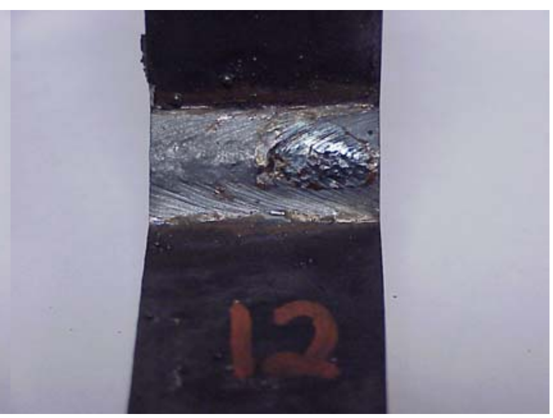




Run 9

Run 10

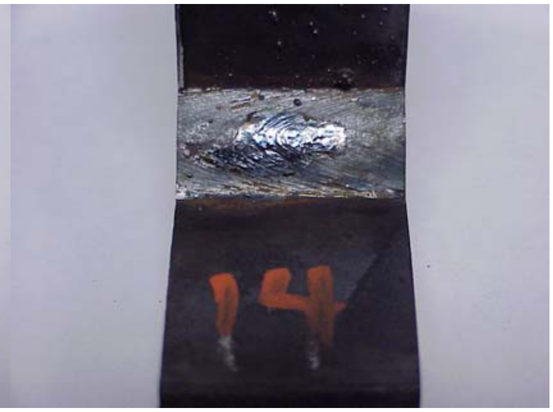




Run 11

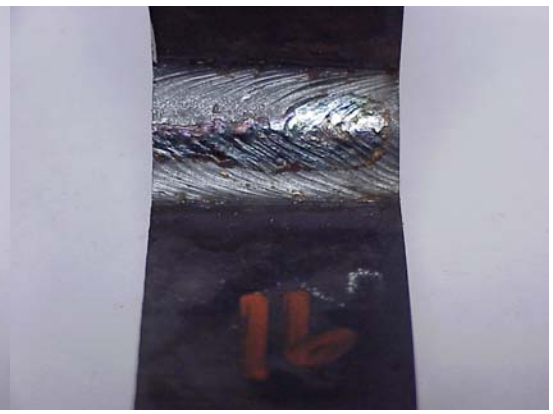
Run 12

Run 13



Run 14

Run 15



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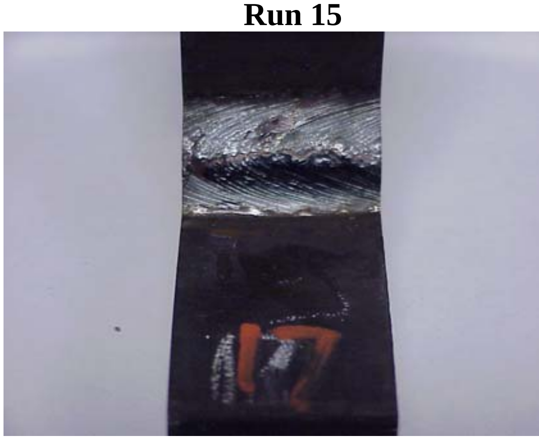
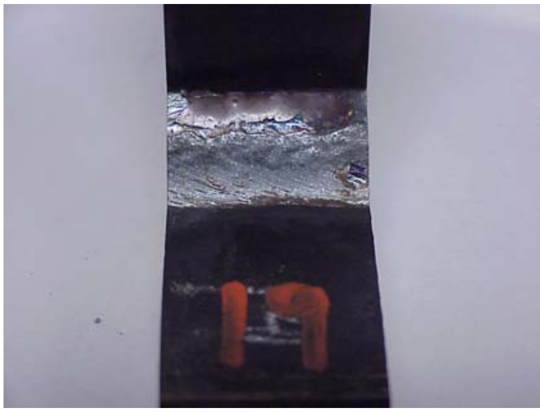


Run 17

Run 18



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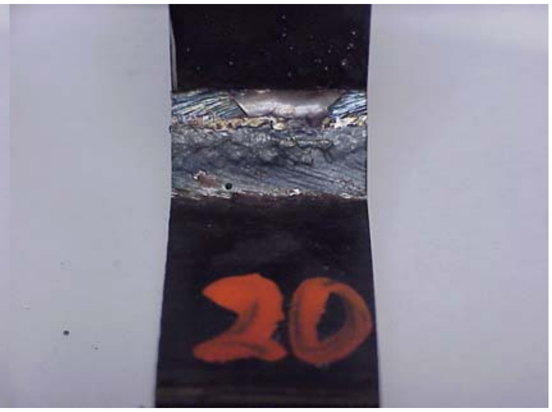
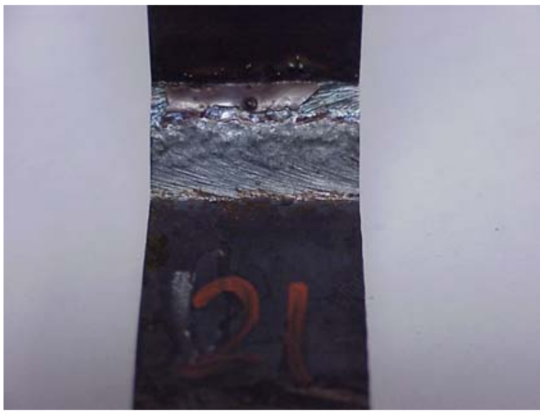
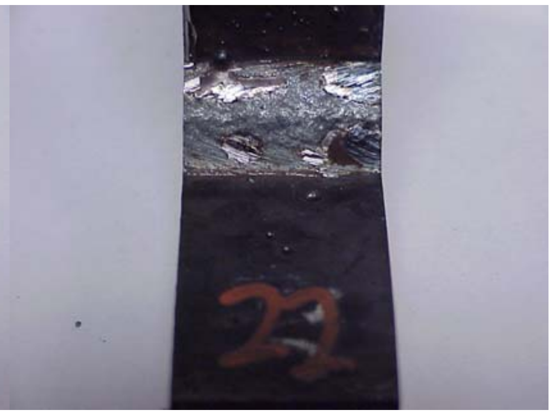


Run 20

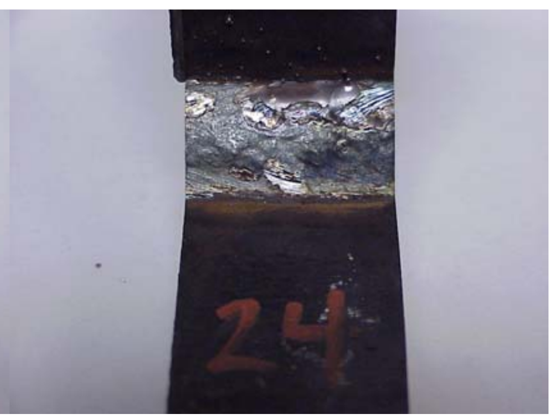


Run 21



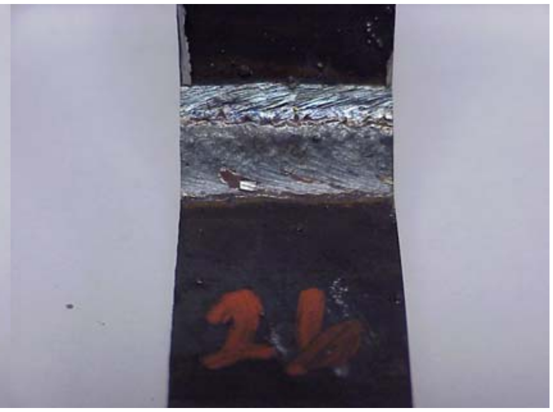
Run 22

Run 23

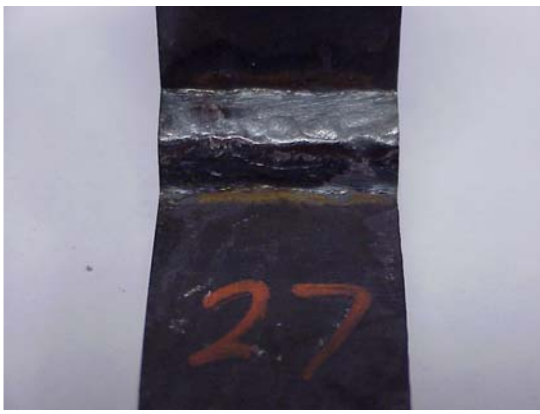


Run 24

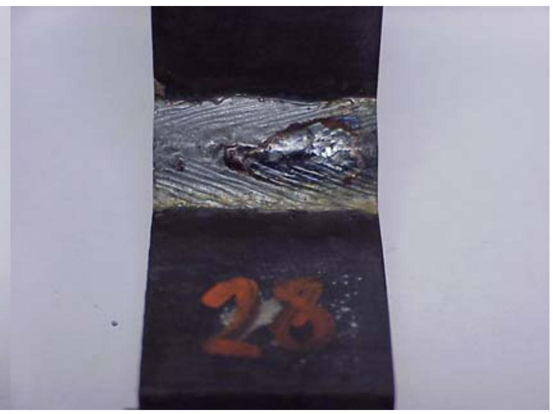
Run 25



Run 26

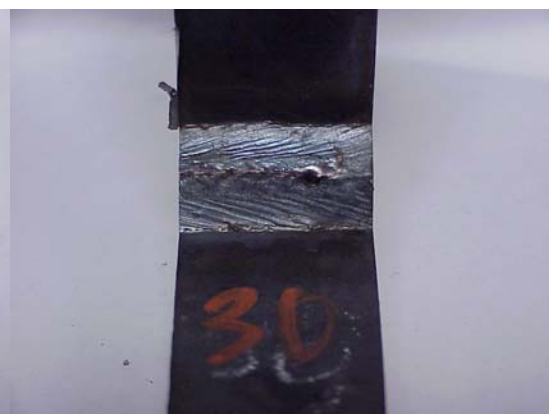


Run 27



Run 28

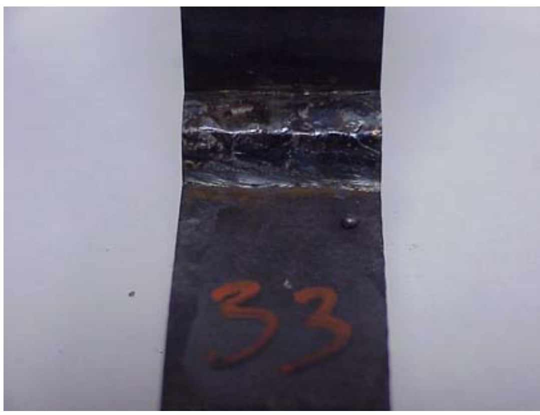
Run 29



Run 30

Run 31

Run 32



Run 33

Run 34